

AD-A170 086

SUPERCONDUCTIVE CONVOLVER WITH JUNCTION RING MIXERS(U)
MASSACHUSETTS INST OF TECH LEXINGTON LINCOLN LAB
S A REIBLE MAR 85 MS-6642 ESD-TR-86-073
F19628-80-C-0002

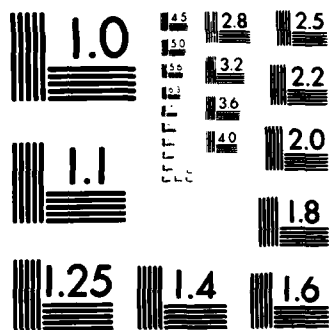
1/1

UNCLASSIFIED

F/G 9/5

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

SUPERCONDUCTIVE CONVOLVER WITH JUNCTION RING MIXERS*

S. A. Reible†

Lincoln Laboratory, Massachusetts Institute of Technology
Lexington, Massachusetts 02173-0073S ÉLECTE
JUL 9 1986

Abstract

A superconductive convolver with tunnel-junction ring mixers has been developed and demonstrated as a programmable matched filter for near 1-GHz-bandwidth chirped waveforms. A low-loss, 14-ns-long superconductive stripline circuit provides temporary storage and relative shifting of signal and reference waveforms. These waveforms are sampled by 25 proximity tap pairs and local multiplication is performed by 25 junction ring mixers. Two short transmission lines coherently sum the local products and deliver the convolution output. The output power level of the convolver has been increased 18 dB by the incorporation of ring mixers and other output circuit improvements. These mixers employ series arrays of niobium/niobium oxide/lead junctions driven by delay-line taps in a quasi-balanced manner. The ring mixer provides higher output power levels (to -58 dBm), improved suppression of undesired mixing products and higher rf impedances than did the single-junction mixers used in the previous device. Convolvers can provide the essential programmable matched-filter component for extremely wide-bandwidth spectral analysis or spread-spectrum communication systems. The current device has a 2-GHz design bandwidth and a time-bandwidth (TB) product of 28. It produced compressed pulses with -7 dB peak-to-side-lobe levels. Design improvements to be discussed include increasing the TB product to 100 and reducing spurious side-lobe levels.

Introduction

The first demonstration of a superconductive convolver was described at the 1982 Applied Superconductivity Conference.¹ This device employed a niobium microstrip line as a low-loss delay element² and single, superconductive tunnel junctions as mixing elements. Because of the low saturation level of the single-junction mixers, the output level of this device was only marginally greater than the thermal noise floor set by wideband room-temperature amplifiers.

Superconductive ring mixers with series arrays of tunnel junctions were developed and incorporated in a new convolver design. The mixer ring provides higher output power levels and, with a quadrature feed, achieves a nominal 10-dB suppression of undesirable mixing self-products. The delay line and device package were redesigned to incorporate a stripline structure resulting in lower phase distortion and more reliable electrical characteristics. Device operation as a wideband programmable matched filter was demonstrated using linearly frequency-modulated (chirped) waveforms.

A convolver can provide the essential signal processing function in communications for wideband spread-spectrum waveforms.^{3,4} The programmable feature of convolvers allows the encoding waveform to be changed from bit-to-bit, thereby providing maximum signal processing flexibility and resistance to repeat jamming and enabling secure communications. Devices with very large bandwidths such as superconductive convolvers can accommodate very high data rates while providing covertness.

*This work was sponsored by the Air Force Office of Scientific Research.

†Present address: MICRILOR, Box 624, Swampscott, MA

Manuscript received 10 September 1984

Convolver Operation

Operation of the superconductive convolver is shown schematically in Fig. 1. A signal $s(t)$ and a reference $r(t)$ are entered into opposite ends of a superconductive delay line. Samples (delayed replicas) of the two counterpropagating signals are taken at discrete points by proximity taps weakly coupled to the delay line. Sampled energy is directed into junction ring mixers which produce mixing products. The mixing products are spatially integrated by summing in multiple nodes connected to one or more short transmission lines. The summed energy which appears at the output port of the device includes the desired cross-product (signal times reference), undesired self-products as well as higher-order terms. Because both of the spatial patterns are moving, there is a halving of the time scale at the output; that is the center frequency and bandwidth are doubled. If the reference is a time-reversed version of a selected waveform, then the convolver functions as a programmable matched filter for that waveform.

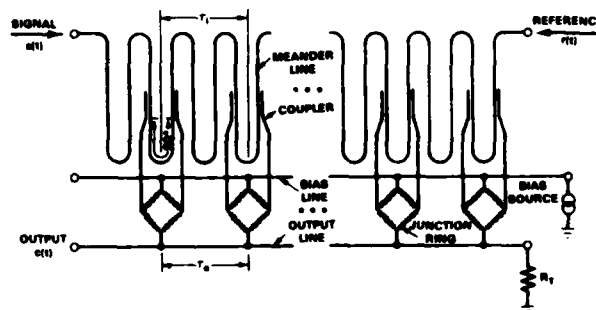


Fig. 1 Schematic of the superconductive convolver.

Convolver Design

Stripline Structure and RF Package

A photograph with an overview of the principal electronic circuitry of an unassembled convolver is shown in Fig. 2. The circuits are fabricated on a 125- μm -thin, $2.5 \times 4 \text{ cm}^2$ sapphire substrate with a niobium ground plane deposited on the reverse side. The central region of the device consists of a 14-ns meander delay line with a 50-ohm characteristic impedance. Twenty-five proximity tap pairs, located along opposite sides of the delay line, sample the propagating waveforms and direct the sampled energy into a corresponding number of junction-ring mixers. The resultant mixing products are collected and summed by two low-impedance (15 ohm) transmission lines located near opposite edges of the rectangular substrate. Each end of the output transmission line has a tapered line section which transforms the characteristic impedance of the line to a standard 50 ohms. The desired outputs from the two transmission lines are then summed externally with a microwave combiner.

During device assembly a second sapphire substrate with another niobium ground plane (shown in Fig. 3) is placed against the delay line region of the first substrate to form a stripline circuit. Alignment of these two substrates to each other is determined by slots which have been machined in the base package. The top sapphire dielectric/niobium ground plane structure

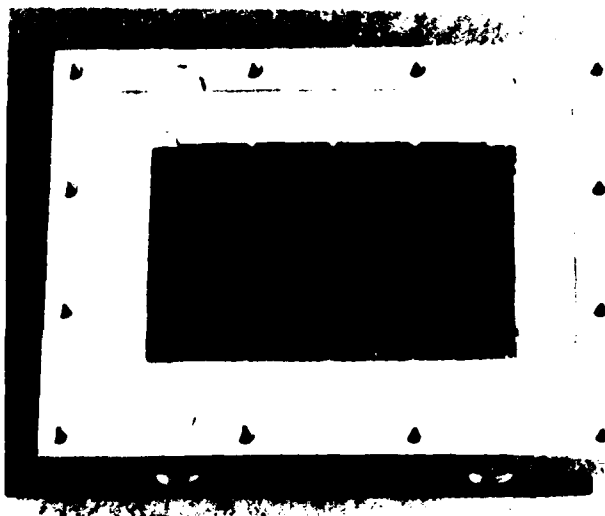


Fig. 2 Sapphire substrate with superconductive circuits mounted in base plate.

extends beyond the edge of the niobium delay line but does not overlap the mixers or output line. A spring insert plate is mounted over the top substrate and 52 beryllium-copper springs are inserted. A central cover plate is then added which compresses the springs and with a nominal 48 newtons of force holds the two sapphire substrates in intimate contact. Wire leads are then bonded to the device pads and RF connectors for electrical connection. Finally, two additional cover plates are added for mechanical protection.

The meander delay line design for this device consists of 78 straight-line sections connected by 180-degree bends. Unfortunately, these bends slightly perturb the line impedance and cause reflections. With careful design, the effects of these reflections can be minimized. Weak coupling between adjacent sections of transmission line is another potential source of reflections. Because the bends are periodically spaced, these reflections add coherently at certain frequencies and produce stop bands in the transmission response of the delay line. These stop bands occur at fundamental and harmonic frequencies of $[2t_d]^{-1}$ where t_d is the delay per section. The design intentionally places the input frequency band (3-5 GHz) between the 1st and 2nd stop bands.

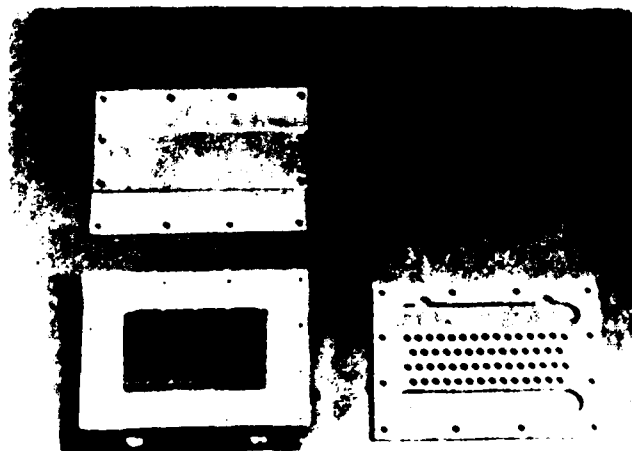


Fig. 3 Photograph of convolver substrates and major package piece parts.

Junction Ring Mixer

The ring mixer has two RF input ports, a single output port and a dc bias port. Each of its active legs has several superconductive tunnel junctions in series. The bias ports are connected to a common current source while the output ports are connected to one of the two output lines. Two terminals on opposite sides of each ring are excited by RF inputs from individual proximity couplers. The two couplers are separated by a nominal 90 degrees on the input delay line and ideally, except for a phase shift, carry equal signal (f_1) and reference (f_2) components to the mixer terminals. The desired mixing term ($f_1 + f_2$) between the signal and reference is coherently summed at the lower terminal of the diode ring and directed into a common output line. In addition to the desired mixing term, undesired self-products of the signal ($2f_1$) and reference ($2f_2$) arrive at the output terminal. But the self-products from the two arms of the ring arrive at the output terminal approximately 180 degrees out of phase and effectively cancel each other. Computer simulation indicates that this technique has the potential of providing a 14-dB suppression of this spurious output over the desired 40% fractional device bandwidth; tests on individual junction ring mixers indicated a nominal 10 dB suppression. A major limitation at the present time is that the sampling weight of the taps is somewhat dependent upon the direction of propagation on the input delay line. Therefore, both input ports of the ring mixer do not always receive the same magnitude of sample of the signal (or reference) waveform. Another limitation is that the proximity couplers are not terminated in their characteristic impedance and that resultant multiple reflections in the couplers can cause considerable phase distortion.

A photograph of a junction ring mixer is shown in Fig. 4. The structure has a series array of four tunnel junction in each of its four legs. The junctions consist of a niobium base electrode, a niobium oxide tunnel barrier and a lead counterelectrode.⁵ Junction areas are defined by 4- μ m-diameter windows etched in a silicon monoxide insulation layer. Input and output signals are coupled into and out of the diode rings through microstrip transmission lines. Stray RF currents on the bias line are terminated with pad-type capacitors.

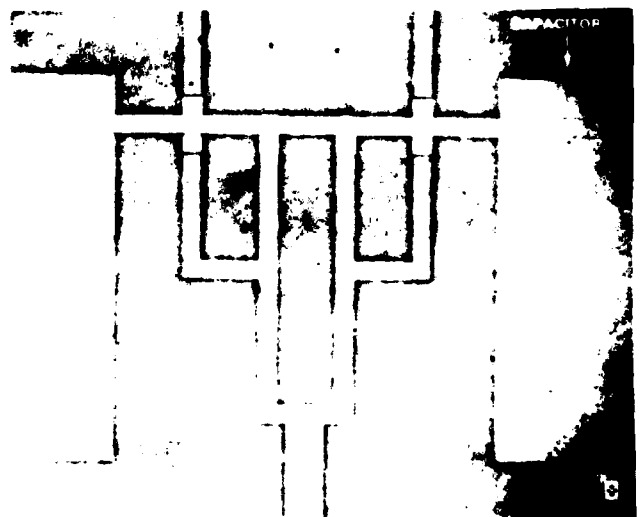


Fig. 4 Photograph of sixteen-junction ring mixer.

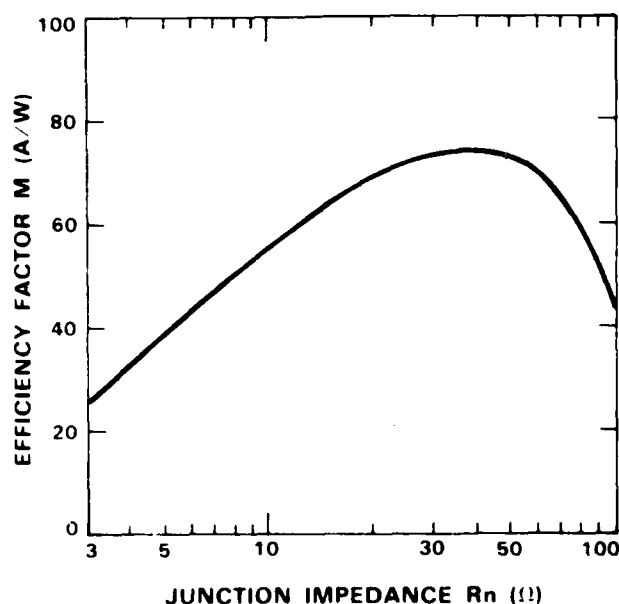


Fig. 5 Predicted efficiency M of ring mixer as a function of normal-state junction resistance (R_n).

To properly design convolvers and to project their performance, it is necessary to have models which predict mixer efficiency and saturation. Nonlinear circuit models which fulfill this function have been developed. The efficiency of the mixing interaction is defined as

$$M = I_T / (P_T P_S)^{1/2},$$

where P_T and P_S are the input powers diverted into the mixer network and I_T is the output current into the load. A plot of the predicted values for M in a convolver structure is shown in Fig. 5. Both M and loading of the output circuit by the ring mixers is strongly dependent upon junction impedance.

Output Circuit

To achieve a properly functioning device, the desired product from each mixer must add in phase at the the output port of the device. Because the collection nodes along the output transmission line are separated by finite delay, excessive phase distortion can result in the superconductive convolver. This phase distortion has been compensated to first order in non-saturating convolvers by offsetting the center frequency of the reference relative to the center frequency of the signal.² This technique is currently employed in the superconductive convolvers. Half of the available output power propagates towards each of the ports at opposite ends of the output line. Since the output phase distortion can only be compensated for one direction of signal propagation, one port of each output line is selected for summation and the second port is terminated in its characteristic impedance. Other frequency terms such as the undesired self-products have a different phase-vs-position relationship and hence usually do not add coherently at the output.

Device Measurements

To determine device characteristics, the convolver was first evaluated with CW input tones. The real-time output of the convolver with CW input tones gated to a

14-ns duration and entered into signal and reference ports is shown in Fig. 6(a). The envelope of the convolver output has a triangular shape as predicted for the convolution of two nearly square (1-ns risetime) input envelopes. The trailing side-lobes are associated with reflections in the measurement set and spurious signals in the device. The convolvers have a measured efficiency factor (F-factor)¹ of -30 dBm which is a nominal 12-dB improvement over the previous design. The maximum output power level of the device (-58 dBm) has been improved by about 18 dB with 12 dB being associated with the use of tunnel junction arrays in the mixers and 6 dB the result of the reduction of parasitic capacitances in the output circuit.

In wideband measurements, input waveforms consisting of a flat-weighted upchirp and a complementary downchirp were applied to the signal and reference ports of the convolver. The waveforms were generated by two superconductive tapped-delay-line filters⁷. The waveforms had chirp slopes of about 62 MHz/ns and were effectively truncated to instantaneous bandwidths of about 0.85 GHz by the 14-ns-long interaction length of the convolver. The resultant output waveform shown in Fig. 6(b) has a bandwidth of about 1.7 GHz. Use of flat-weighted chirps should yield a $(\sin x)/x$ response with a null-to-null width of 1.2 ns and peak relative side lobes of -13 dB. A null-to-null width of 1.5 ns was observed with excessively high -7 dB side-lobe levels. These distortions are attributed primarily to mixer products produced from undesired leakage of input signal onto the output line and inadequate balance in the taps.

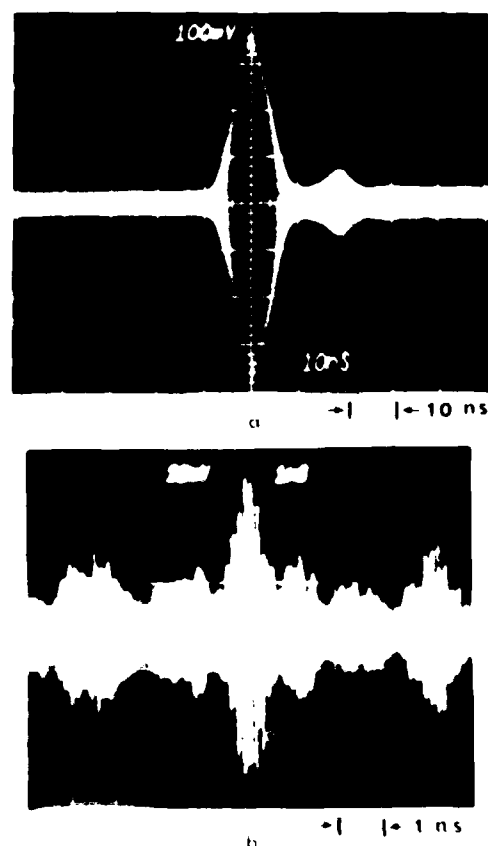


Fig. 6 Output waveform of junction ring convolver with inputs (a) of two 14-ns-duration gated CW input tones and (b) of two linearly chirped waveforms.

Extending Time-Bandwidth Product

The maximum potential signal-processing gain of an analog device is equal to its time-bandwidth (TB) product, where T , the interaction time, is the total delay length of the device over which the waveform is adequately sampled and B , the bandwidth, is limited to the frequency range over which the amplitude and phase response of the device is well behaved. Adequate sampling requires that the time delay between any two complex samples of the waveform not exceed $1/B$. The convolver design described in this report has a maximum tap-delay spacing of about 0.47 ns, for a potential signal processing bandwidth slightly greater than 2 GHz, and a delay time of about 14 ns; thus it has a nominal TB product of 28. Progress has been made in both the technology required to realize longer interaction lengths⁸ and in conceptual designs which incorporate substantially larger numbers of composite tap/mixer sections.

A "daisy-wheel" delay line structure, shown in Fig. 7, has been conceived and investigated as an alternative to the present "meander-line" structure. The modified structure will maximize the utilization of surface area on the round substrates. To have a TB product of 100, a like number of mixers is required. The mixers and output lines will be located around the outer edges of the "daisy-wheel" design. A new tap design with a symmetrical structure and very short transmission lines leads will improve "mixer balance" for improved spurious suppression. Design studies indicate that a convolver with a TB product of 100 can be fabricated on 125- μ m-thick, 7.6-cm-diameter substrates. Silicon and sapphire substrates with these dimensions are commercially available. Thinner substrates under development at Lincoln Laboratory would allow much greater circuit density and correspondingly larger convolver TB products.

Discussion

Significant improvements have been realized in the development of a superconductive convolver for wideband analog signal processing. A new convolver design has been designed, fabricated and characterized with CW bursts and wideband waveforms. The new design is providing an 18-dB improvement in output power level. Present spurious signal levels are unacceptably high and design improvements have been proposed. Current technology would support the development of a superconductive convolver on a single dielectric substrate with a bandwidth of 2-5 GHz and a TB product of 100.

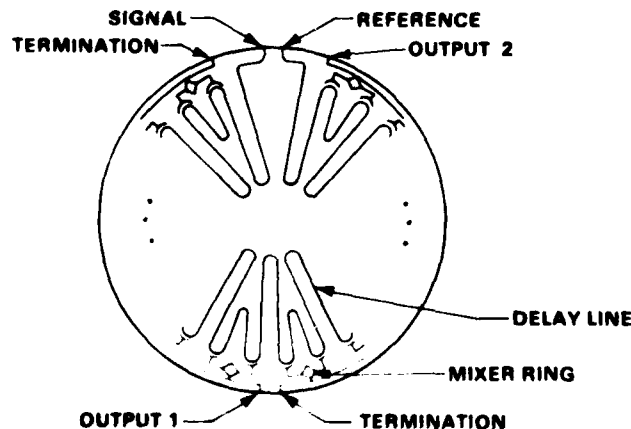


Fig. 7 Proposed "daisy-wheel" convolver structure.

Acknowledgements

The author gratefully acknowledges R. W. Ralston and J. H. Cafarella for their advice and guidance, E. M. Macedo for his reactive ion etching and tunnel junction work, R. S. Withers and A. C. Anderson for the superconductive tapped delay lines, J. H. Holtham for computer programming, A. P. Denno and G. L. Fitch for photomask generation, C. M. Vanaria and P. R. Phinney for photolithography, J. Hamer for niobium films, and S. S. Cupoli for measurements.

REFERENCES

1. S. A. Reible, A. C. Anderson, P. V. Wright, R. S. Withers and R. W. Ralston, "Superconductive Convolver," IEEE Trans. Magn., vol. MAG-19, no. 3, pp. 475-480 (1983).
2. S. A. Reible, "Wideband Analog Signal Processing with Superconductive Circuits," 1982 Ultrasonics Symp. Proc. New York: IEEE, 1982, pp. 190-201.
3. J. H. Cafarella, J. A. Alusow, W. M. Brown and E. Stern, "Programmable Matched Filtering with Acoustoelectric Convolvers in Spread-Spectrum Systems," 1975 Ultrasonics Symp. Proc. New York: IEEE, 1975, pp. 205-208.
4. S. A. Reible, "Acoustoelectric Convolver Technology for Spread Spectrum Communications," IEEE Trans. Microwave Theory and Tech., vol. MTT-29, no. 5, pp. 463-473 (1981).
5. S. A. Reible, "Reactive Ion Etching in the Fabrication of Niobium Tunnel Junctions," IEEE Trans. Magn., vol. MAG-17, no. 1, pp. 303-306 (1979).
6. E. L. Adler, "Electromagnetic Long-Line Effects in SAW Convolvers," 1980 Ultrasonics Symp. Proc. New York: IEEE, 1980, pp. 82-87.
7. R. S. Withers, A. C. Anderson, P. V. Wright, and S. A. Reible, "Superconductive Tapped Delay Lines for Microwave Analog Signal Processing," IEEE Trans. Magn., vol. MAG-19, no. 3, pp. 480-484 (1983).
8. R. S. Withers, A. C. Anderson, J. B. Green and S. A. Reible, "Superconductive Delay-Line Technology and Applications," to be presented at the 1984 Applied Superconductivity Conference, San Diego, CA.

Accession	
NTIS	
DTIC	
Uncl	
Class	
By	
Distrib	
Available	
Dist	Special
A-120	

AD-A170 086

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESD-TR- 86-073	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Superconductive Convolver with Junction Ring Mixers		5. TYPE OF REPORT & PERIOD COVERED Journal Article
7. AUTHOR(s) Reible, Stanley A.		6. PERFORMING ORG. REPORT NUMBER MS-6642
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lincoln Laboratory, M.I.T. P.O. Box 73 Lexington, MA 02173		8. CONTRACT OR GRANT NUMBER(s) F19628-80-C-0002
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Systems Command Andrews AFB Washington, DC 20334		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 649L
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Electronic Systems Division Hanscom Air Force Base Bedford, MA 01730		12. REPORT DATE 10 September 1984
		13. NUMBER OF PAGES 4
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE n/a
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES IEEE Transactions on Magnetics, Vol. MAG-21, No. 2 March 1985		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Superconductive convolvers, Tunnel-Junction ring mixers, chirped waveforms,		
<p>A superconductive convolver with tunnel-junction ring mixers has been developed and demonstrated as a programmable matched filter for near 1-GHz-bandwidth chirped waveforms. A low-loss, 14-nm-long superconductive stripline circuit provides temporary storage and relative shifting of signal and reference waveforms. These waveforms are sampled by 25 proximity tap pairs and local multiplication is performed by 25 junction ring mixers. Two short transmission lines coherently sum the local products and deliver the convolution output. The output power level of the convolver has been increased 10 dB by the incorporation of ring mixers and other output circuit improvements. These mixers employ series arrays of niobium/niobium oxide/lead junctions driven by delay-line taps in a quasi-balanced manner. The ring mixer provides higher output power levels (to -30 dBm), improved suppression of undesired mixing products and higher rf impedances than did the single-junction mixers used in the previous device. Convolvers can provide the essential programmable matched-filter component for extremely wide-bandwidth spectral analysis or spread-spectrum communication systems. The current device has a 2-GHz design bandwidth and a time-bandwidth (TB) product of 28. It produced compressed pulses with -7 dB peak-to-side-lobe levels. Design improvements to be discussed include increasing the TB product to 100 and reducing spurious side-lobe levels.</p>		

END

DTIC

9-86